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LONGWALL GATESIDE PACKS: PART 1
A REVIEW OF PACKING SYSTEMS

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LONGWALL GATESIDE PACKS: PART 1
A REVIEW OF PACKING SYSTEMS

by

P. Cain*

ABSTRACT

A review of the requirements of gateside packs followed by descriptions of traditional packing methods and cement based monolithic packing systems is presented. Laboratory and in situ properties of the various pack types are discussed and their implications in pack design reviewed.

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MURS DE REMBLAI DES TAILLES À LONG FRONT ALIGNÉ: PARTIE 1
EXAMEN DES SYSTÈMES DE REMBLAYAGE

par

P. Cain*

RÉSUMÉ

Le rapport présente un étude des exigences relatives aux murs de remblai ainsi qu'une description des méthodes classiques de remblayage et des systèmes de remblayage monolithiques basés sur l'utilisation du ciment. On examine les caractéristiques des divers types de remblayage, en laboratoire et in situ, ainsi que leurs répercussions sur la conception des remblais.

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INTRODUCTION

The decision to implement monolithic packing in the Sydney Coalfield as a measure to reduce gob leakage and to improve face end efficiency presupposes an adequate knowledge of the types of monolithic packing available, the physical properties of such packs and an engineering approach to their design in order to fully realise the substantial improvements in efficiency and support demonstrated elsewhere.

The purpose of this report is to document, through the author's personal experience, literature evaluation and visits made to mining research facilities and underground mines in Europe, the variety of monolithic packing systems available and their applicability to conditions existing in the collieries run by the Cape Breton Development Corporation. Included is a review of the requirements of gateside packs, a description of traditional packing methods, descriptions of the major cement-based monolithic packing systems currently in use and an evaluation of the physical properties of monolithic packs. Concepts applicable to the design of gateside packs and their evaluation under Sydney Coalfield conditions will be discussed in a companion report to be entitled "Longwall Gateside Packs: Part II Design Concepts and their Application in the Sydney Coalfield" and completed by July 1985.

REQUIREMENTS OF GATESIDE PACKS

The most important functional requirement of a gateside pack is that it provides adequate support at the waste edge to prevent excessive gateroad closure and to maintain a good break-off line to prevent the gob from encroaching on the gateroad. Additional requirements include the prevention of undue air leakage across the gob, and traditionally a convenient disposal area for brushing debris.

The support function can be discussed in two stages: the early load bearing stage, and the long term load bearing stage.

EARLY LOAD BEARING

In the early load bearing stage of pack life the prime requirement is to support the cantilever of roof strata extending from the solid ribside

to the waste edge over the gateroad and the pack at the face end. Failure to support this cantilever will result in bed separation and excessive bending or fracture of the beam. In this case, high rates of closure at the face end and poor roof conditions can be expected to occur, with the consequent danger of falls of ground, poor access and reduced ventilation efficiency.

The support requirement at this early stage is therefore the support of the weight of the cantilever of roof strata. This can be approximated by deriving the mass of the beam to be supported and dividing it by the area of the pack. Thus a 2 m wide pack for a 4 m wide roadway associated with a 2 m extraction should provide a resistance of approximately 0.3 MN/m^2 (50 psi) to maintain the remnant cantilever, generally considered to extend to about twice the extracted height above the roof of the seam. This resistance should be available immediately after the packhole supports are moved forward.

As the gateside pack is a passive form of support, some deformation is inevitable in order to generate a stabilising resistance. Very low pack stiffness, poor filling of the packhole and excessive pack to face distances all contribute to excessive deformation prior to stabilization, which may result in the deterioration of the roof strata and the onset of the problems described above. In addition to creating problems in the early load bearing stage, deterioration of the roof strata reduces any inherent strength with the consequence that closure in the long term becomes more difficult to control.

LONG TERM LOAD BEARING

As the coalface moves away from the pack, strata overlying the extracted seam caves into the void created. Although the caved strata initially increases in volume to prevent caving above a height over the seam corresponding to 2-4 times the extracted section, the resistance of the broken material is such that subsidence of strata bridging the caved zone is inevitable during recompaction of the broken material. The subsidence profile at seam level is related to surface subsidence and extends into the ribside a distance governed by, among other things: depth, width of extraction, extracted section and the mechanical properties of the strata. The subsidence profile imposed on the gateroad supports generates loading and deformation. In this stage of deformation it is the function of the pack to

maintain an even load distribution. Too weak a pack will allow excessive tilt of the bridging beds into the gob and the deterioration of the roof beam, and too strong a pack will promote bearing failure of the roof or floor with the same result.

GATESIDE PACKING METHODS

The formation of gateside packs can be accomplished by either the traditional methods of hand building, mechanical packing or pneumatic stowing, or by the more recently developed application of cementitious pack materials.

TRADITIONAL METHODS

Hand Built Packs

In the past, the most common method of packing by hand was the building of stone packs. Cobble-sized ripping debris was arranged in walls and infilled with smaller dirt and coal duff. Such packs have the following disadvantages:

(a) they are difficult and time-consuming to build, requiring skilled and careful work for full effect;

(b) the pack walls, which take most of the early load, may fail unless carefully built;

(c) the core of the pack does not give a great deal of support until quite large convergence has occurred; and

(d) the final strength of the pack is ultimately controlled by the skills of the packers and the material available.

For these reasons such packs have been largely abandoned in favour of other types that are more efficient in construction and strata control. Efforts were made to improve the quality of stone packs by reinforcement with wire mesh[1] or by filling the stone into bags, and building a pack with the filled bags[2]. Both of these resulted in better lateral stability, but they did not assist in the greater problem of providing early resistance to roof lowering.

Wooden packs in the form of pillars or cogs made from pre-cut hard or soft wood can be built very quickly and easily, filled with dirt if required, and wedged against the roof providing an effective early support. The effect of wedging - the amount by which the chock can be preloaded - has been examined by Margo and Bradley[3]. They found that a preloading of 8.2 KPa was possible using wedges and a 4 kg hammer in cogs constructed in South African Mines. The setting load imparted by wedging decays as creep of the timber occurs[4]. Wooden packs thus have advantages over stone packs, but they require the importation of large quantities of material to the face end.

In the U.K. especially, a more telling disadvantage of timber packs was their high cost. In the late 1960's and early 1970's, the shortage of suitable home-grown timber and the high cost of imported alternatives prompted research into the development of wood substitutes for use in mining. Important considerations were[5]:

(1) comparable price,

(2) comparable load/yield characteristics,

(3) similar dimensions and handling weight, and

(4) robustness in transport,

Work by Lewis[5] in the U.K. and by McChesney[6] in South Africa, highlighted the applicability of Autoclaved Aerated Concrete blocks with internal or external wire mesh reinforcement. Pomeroy[7] has described the modification of concrete properties by the addition of polymers and Wood[8] has described the use of polymer-modified concrete blocks in gold mines in South Africa, where natural polyisoprene proved an efficient admixture for lowering the Young's Modulus and preventing crumbling of the concrete blocks. The rise in oil prices has made polymer modification of concretes expensive for mine use, despite their strength advantages.

Composite packs consisting of wood cogs and stowed dirt may be used to reduce the quantity of wood required and to reduce the amount of dirt in the run of mine product. In South Africa, composite cogs of alternating wood and concrete layers have been used to improve strata control[9] and they have shown advantages over wood cogs[4,10].

Mechanically Built Packs

Mechanical packing methods were developed for the following reasons:

(a) to speed up the packing operation, and so allow more rapid face advance,

(b) to reduce the number of non-productive personnel, and

(c) to improve strata control.

In most applications mechanically built packs achieve the first two of these but in some circumstances the lack of a roadside wall weakens the roadway shoulder above the pack, decreasing the roadway stability and increasing support damage[11].

The technical benefits of mechanical packing have been described as[12]:

(a) better consolidation of packing material, and efficient construction to the roof,

(b) less roadway closure,

(c) complete disposal of dirt,

(d) minimization of the amount and cost of imported packing materials,

(e) reduction in the risk of spontaneous combustion, and

(f) increased utilization of shaft capacity as the dirt is left underground.

The main methods of mechanical packing are:

(a) Slusher Packing,

(b) Blade Packing, and

(c) Ram Packing.

Although the number of mechanised packing installations is increasing very slowly, usage of individual methods varies with slusher packing on the decline, blade packing steady, and ram packing increasing in usage[13].

Slusher packing installations comprise over 50% of mechanical packing installations. In its simplest form, a bucket is loaded with ripping dirt from the roadway and hauled by rope into the packhole where it empties and returns. Good compaction is difficult to achieve and the rate of packing (15-20 tonnes per hour) is low. Typical installations are described by Bell[14], Naylor and Thompson[15], and Carr and Kitching[13].

Several types of Blade Packing installation are currently in use[12,13]. A blade or plough mounted on a hydraulically driven chain collects debris from a platform in the road and pushes it to the end of the packhole where it is compacted by the force of the blade. The blade then returns to the roadway. Packing rates of 40-50 tonnes per hour can be achieved.

Ram Packing is conducted in a similar manner but the debris is moved into the packhole by rams mounted on the rear of the face support. Good compaction can be achieved.

Pneumatically Stowed Packs

Pneumatic construction of packs is accomplished by transporting the packing material by means of compressed air to the packhole, where it is blown into place. Ripping material or other dirt can be stowed on its own, or reinforced with cements or resin[15], or a naturally cementitious material such as anhydrite can be emplaced pneumatically with an activator (water) and an accelerator to form a high-strength roadside pack. There are two methods of placing packs pneumatically, using either high pressure or low pressure air flows[12,13,16].

High pressure stowing units comprise a compressed air stower and delivery pipes. Capital costs are lower and if a continuous feed can be achieved, up to 50 tonnes per hour of material can be emplaced in a high quality pack using a compressed air pressure of 0.4 - 0.6 MPa. This method suffers from the major disadvantages of excessive noise and dust. Low pressure stowing, despite its higher capital cost, is more environmentally acceptable.

Low pressure stowing units operate at pressures of only 0.08 MPa and are soundproofed. They require, however, a controlled graded feed of - 8 cm material, the remainder being sent out of the district in the normal way. The pack quality is again good but dust can be a major problem, as well as the cost and complexity of the system.

Cuckow and Walton[17] have investigated the dust made during pneumatic stowing operations. Whetton and Sinha[18] have conducted investigations into the desirable characteristics of stowed material, although in the context of full face stowing.

A development of pneumatic packing pioneered in West Germany and recently applied in the United Kingdom, has been the use of natural anhydrite

which is mixed with a water/accelerator mixture at the stowing outlet[19-23]. Anhydrite and the potassium/ferrous sulphate used as an accelerator are transported underground. The accelerator is mixed with water and pumped to the packhole where it meets the anhydrite, which can be transported for distances of up to 1000 m in 10 cm diameter hardened pipes from an injector unit which can be of the continuous on intermittent type. The packhole itself is lined with brattice, but complete sealing is not required and the water/accelerator mixture acts to damp down the dust. The resulting packs set very rapidly (after 5 hours the compressive strength is 8 MPa) and in general are constructed 1-2 m wide. This method forms part of the range of packing methods utilising cementitious materials.

METHODS UTILISING CEMENTITIOUS MATERIALS

Packing methods utilising cementitious materials are usually described as monolithic packing methods. Monolithic packs may be emplaced pneumatically (described above) or hydromechanically; the binding agent is anhydrite or cement. The interrelationship of the various monolithic systems is shown in Figure 1.

HYDROMECHANICAL PACKING

Hydromechanical packing methods form the major part of the monolithic packing methods, one of which has already been described. The method stemmed from attempts to reduce the cost of pneumatically emplaced natural anhydrite by using the cheaper but finer grained synthetic anhydrite, a by-product of certain industrial chemical processes. Pneumatic emplacement was not possible without the use of costly brattice bags with complicated dust filters[24,25], and so hydromechanical methods of emplacement were developed. Experiments with alternatives to anhydrite as the active constituent has lead to a wide range of quick setting filler, cement and cement/aggregate based systems being developed.

Emplacement of Packs

The procedure in all types of hydromechanical packing is similar. It involves the mixing of the active ingredient with water and pumping it to

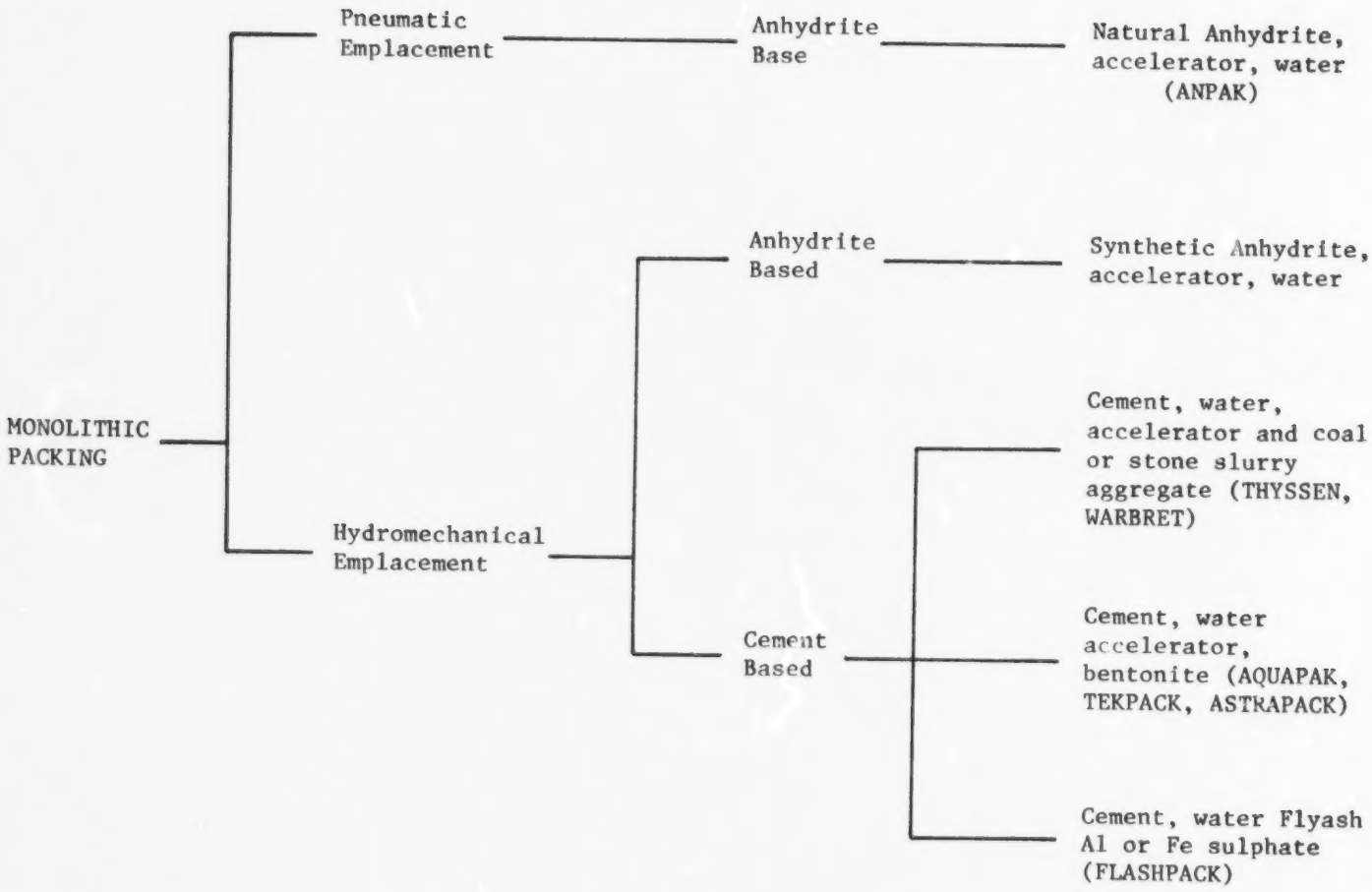
MONOLITHIC PACKING
Pneumatic Emplacement
Anhydrite Base
Natural Anhydrite, accelerator, water (ANPAK)
Hydromechanical Emplacement
Anhydrite Based
Synthetic Anhydrite, accelerator, water
Cement Based
Cement, water, accelerator and coal or stone slurry aggregate (THYSSEN, WARBRET)
Cement, water accelerator, bentonite (AQUAPAK, TEKPACK, ASTRAPACK)
Cement, water Flyash Al or Fe sulphate (FLASHPACK)

Figure 1 - Interrelationship of monolithic packing systems

the packhole. The pumping distance depends on the rapidity with which the active medium sets. An accelerator may be used, in which case it is mixed with either the active ingredient thus reducing the pumping distance, or another water supply which joins the grout supply at the packhole. In order to reduce grout costs, an aggregate may be used which is pumped to the packhole in a water/bentonite suspension and mixed with the grout. The accelerating agent may be included in the aggregate mixture.

Synthetic Anhydrite Packs[24,26]

In normal practice, synthetic anhydrite packs are stowed hydromechanically in order to prevent dust hazards. The difference in grain size between natural and synthetic anhydrite is shown in Table 1. The size difference is reflected in the water:solids ratio and the filling factor, but despite this, the two methods of packing produce packs of similar properties.

The pack is emplaced by emptying bags of synthetic anhydrite at a steady rate into a paddle mixer. A water/accelerator mixture is admitted to the paddle mixer at a steady rate, thus producing a uniform slurry which is pumped by a reciprocating pump along the delivery line to the prepared and sealed packhole. Because the anhydrite has been activated, only short distances can be pumped and the pumping station is usually moved along in step with the faceline.

THE DEVELOPMENT OF CEMENT BASED SYSTEMS

Cement based packing systems development has been, almost exclusively, the product of research in the United Kingdom addressed to the mechanisation of the packing process and the requirements of efficient pack sealing in seams liable to spontaneous combustion.

The first system developed was the Thyssen system in 1973 followed by the Warbret system. Both systems utilise coal fines or development waste as a filler. Early difficulties with aggregate slurry pumping lead to the development of the water based packs, which were soon followed by systems requiring less material. The constituents of the major systems are given in Table 2.

All the systems are hydromechanical and utilise two mixers, pumps and pipe ranges. This involves quite high capital costs at the initial installation phase but once the method is applied, considerable benefits in

Table 1 - Grain size distribution of natural and synthetic anhydrite

Type	Grain size, % by Weight				Filling Factor (t/m^3)	Water:Solids Ratio Required
	>0.5 cm	0.2-0.5 cm	0.1-0.2 cm	<0.1 cm		
Natural Anhydrite[1]	70	10	4	16	2.15	0.1
Synthetic Anhydrite[2]	4	15	23	58	1.35	0.36

[1] crushed raw anhydrite, as mined

[2] bagged $CaSO_4$, fertilizer industry by-product

Table 2 - Constituents of the major cement based packing systems

	Thyssen	Warbret	Aquapack	Tekpack	Astrapack	Flashpack
Cement	Packbind	O.P.C.	Aquacem	Tekcem	N/A	O.P.C.
Aggregate/Filler	-2 cm R.O.M. coal or dirt	-2 cm R.O.M. coal or dirt	Bentonite/Water			Fly Ash
Accelerator	In cement	TEA 51 in Aggregate	Na carbonate in bentonite			Al or $FeSO_4$ in Fly Ash
Mix Ratios % by weight						
Cement	11	19	14	14	14	19.7
Accelerator		2				7.7
Bentonite	1	1	1	14	14	1
Aggregate	66	48	-	-	-	71.8
Water	22	30	85	72	72	32

strata control, ventilation, productivity and safety are often realised. In the United Kingdom, cement based pump packing systems comprise 10% of all face end support systems currently installed (September 1983). In the rest of Europe, monolithic systems are almost exclusively anhydrite based, with the largest use being in Germany.

The Thyssen System[28,29,30]

A specially manufactured quick-setting cement, i.e. an accelerated cement, is slurried in a paddle mixer in a similar manner to the synthetic anhydrite but when it reaches the packhole it is mixed with six times its weight of a water/bentonite/aggregate slurry, mixed and pumped from outbye or from the surface. The delivery range for the grout must be kept short (300-500 m in practice) in order to prevent blocking of the range by setting of the cement.

In this method of packing the planned aggregate was -2 cm sized coal, but its use has been extended to colliery development waste. Use of this material has presented a problem in that the bentonite is not sufficiently mixed to absorb enough water to prevent it from drying the slurry and causing pipe blockages. Currently, development waste is successfully being pumped from surface at Daw Mill Colliery using a pre-mixed bentonite suspension.

The Warbret System[31]

In many respects, the more recently developed Warbret system of packing is similar to the Thyssen system. The major differences between the systems are:

(1) The cement used is ordinary Portland cement.

(2) The accelerator, an organic compound specially developed by the NCB Mining Research and Development Establishment (MRDE) for use with Ordinary Portland Cement (O.P.C.), is added to the coal slurry thus increasing the pumping distance of the grout.

(3) The bentonite is premixed with the water for the aggregate slurry in special mixing tanks. This enhances the flow properties and prevents clogging of the delivery range.

The Aquapack System[32]

A rapidly setting, specially developed cement, 'Aquacem' is mixed in a paddle mixer to form a slurry and pumped to the packhole. A parallel mixer and pump conveys a premixed water/bentonite and accelerator to the packhole where it is mixed with the grout before entering a brattice bag. The bentonite prevents the cement slurry from settling out and an acceptable pack can be prepared with a water/cement ratio of 17:3 by weight.

The advantages of the system are threefold:

(1) less cement is used,

(2) coal is not lost to the pack, and

(3) the equipment is simple.

The Tekpack/Astrapack System[33]

Tekpack and Astrapack are competing proprietary brand names of a low solids content water based packing system developed by the NCB. They were developed in an attempt to reduce the material requirements and represent a 27% reduction in weight of material brought into the mine for each cubic metre of pack.

The method of emplacement is identical to that of Aquapack, the main difference between the systems being the formulation of the cement, the inclusion of the cement accelerator in the bentonite suspension, and a higher quantity of bentonite in the Tekpack/Astrapack systems. As well as lower material requirement, the material cost is substantially less and the cement grout component has a longer pumping life due to the inclusion of the accelerator in the non-setting bentonite component.

The Flashpack System[34]

The beneficial effects of flyash addition in some concrete uses have been known for some time and cement/flyash mixtures have been used for gateside packing for many years in Japan.

The Flashpack system developed by MRDE employs two grout mixing tanks and pumps with delivery tubes connected to an ejector nozzle at the packhole. One mixer produces a 4:6 mix of cement and water, the other a 10:4:1:1 mix of flyash, water, accelerator and bentonite. The Flyash grout is stable for up to four days, and may be premixed and pumped from the surface. The cement grout, using O.P.C., has about a 500 m pumping distance

limit. The two grouts are pumped at rates allowing a 3:1 Flyash grout/cement grout mix at the mixing nozzle and sufficient velocity to allow the material to be sprayed to the back of the packhole. The mix gels almost immediately on mixing and can be built up like shotcrete in a packhole defined by steel sheeting. The pack is quite firm after 20 minutes. Packing rate can be 22 m^3/hour.

PACK PERFORMANCE

THE ASSESSMENT OF PACK PERFORMANCE

Pack performance is generally considered by examining the stress/strain relationship. The method of plotting stress as a percentage of the failure or yield stress gives only qualitative results and is to be avoided. An idealised load/compression curve for a mine support has been presented by Blight[35] (Fig. 2) who gives the following desirable characteristics:

(1) A large primary deformation modulus (E_p),
(2) A consistently predictable yield load or stress (P_y),
(3) A low (zero or positive) secondary deformation modulus (E_s), and
(4) A large useful compression (C_u).

The performance of materials in general is usually given in terms of the Young's Modulus and the yield stress, and after the material has failed, i.e. the yield stress has been exceeded and the sample has broken, it is usually of no further use. Pack materials are expected to give support even after failure, and the parameters of Young's Modulus and Yield Stress are insufficient to fully describe such behaviour.

As already described, Blight[35] has given four parameters that may be used to describe the behaviour of passive roadway supports. Carr[36] has described the calculation of a Modulus of Deformation for monolithic concrete/coal aggregate pumped packs. Lewis[5] in his work on substitutes for timber in underground supports reported the use of a measure of Pack Performance Efficiency in order to compare various types of pack material. The Pack Performance Efficiency (P.P.E.) was based on the energy adsorption during the

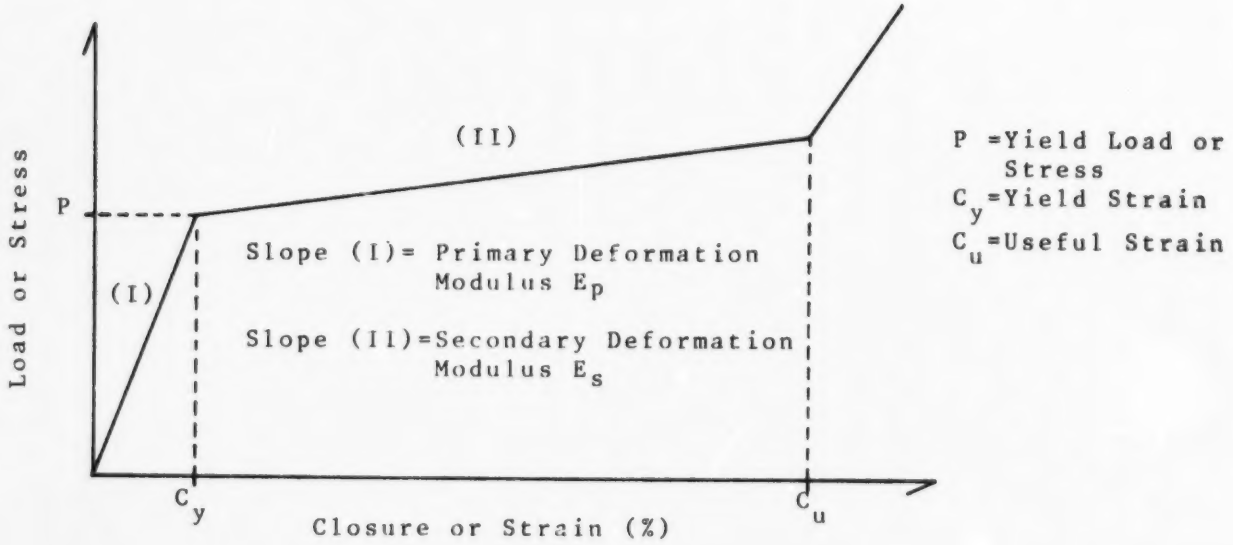

Figure 2 - Idealised load/compression curve for a mine support

initial 30% of compression. The calculation of P.P.E. is shown in Figure 3. The P.P.E. can also be calculated for other compressions and defined thus:

$P.P.E._{30}$ Performance Efficiency at 30% Compression

$P.P.E._{20}$ Performance Efficiency at 20% Compression

and so on.

COMPARISON OF PACK TYPES

When considering the properties of packs, three types can be defined:

(1) Packs made of loose material, which require excessive convergence to develop reasonable resistance. Packs in this category include hand and mechanically built stone packs, with or without reinforcement.

(2) Prefabricated packs, i.e. those packs made from wood or concrete blocks, or combinations of these, including filled cogs.

(3) Monolithic Packs: Anhydrite, Cement or Quick Setting Filler mixtures emplaced pneumatically or hydromechanically.

Each of these types will be discussed in turn.

Loose Fill Packs

Published data concerning loose fill packs is largely restricted to hand built stone packs, as mechanically built packs are very difficult to instrument effectively. Resistance does not develop until convergence has caused the compaction of the fill and quite large compressions are required in order to develop load. The following figures have been published for shale rubble, coal rubble and undefined 'loose fill'[37]:

Shale Rubble at 35% vertical strain, 0.6 MN/m^2

Coal Rubble at 30% vertical strain, 0.5 MN/m^2

Loose Fill at 20% vertical strain, 0.2 MN/m^2

Evans and Henshaw[38] have reported tests on stone packs in the laboratory and underground. Barraclough et al[39] have also experimented on stone packs in the laboratory. The latter were restricted to the compaction stage of the stress strain curve due to premature failure of the packs under test.

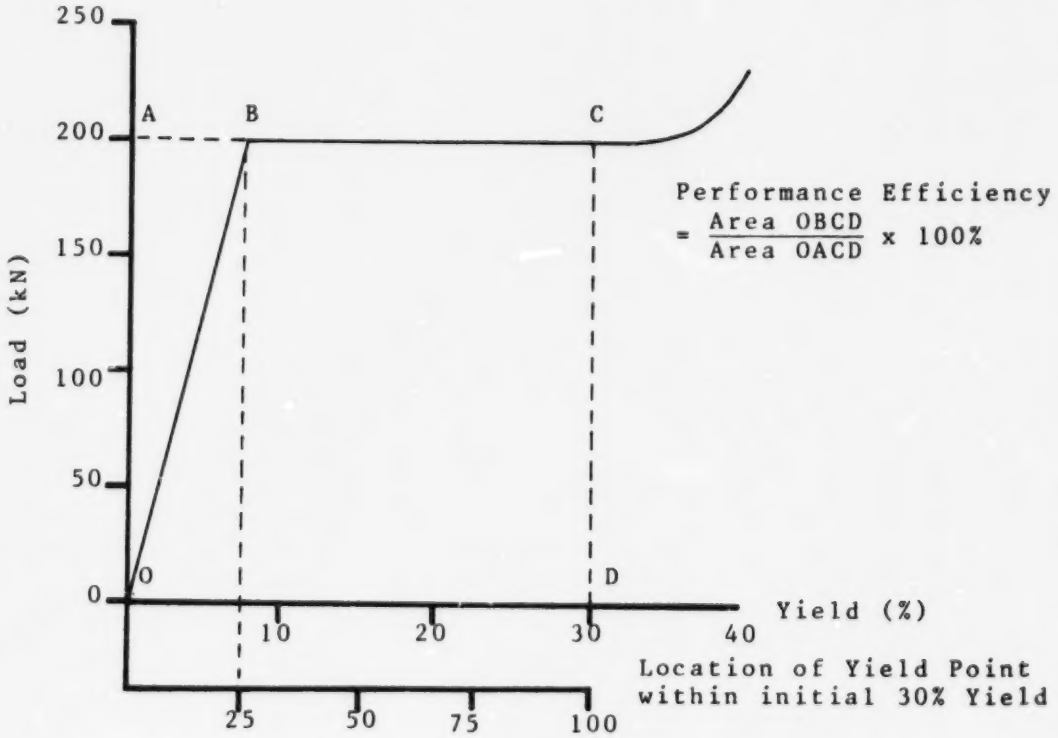

Figure 3 - Calculation of pack performance efficiency

Stone packs have no recognisable yield load and the major part of the load is carried on the confined centre of the pack. The provision of lateral restraint by either of the methods described previously has not been assessed, although the improvement in conditions created by their application is due to the increase in stability. Qualitative comparisons of hand filled, bagged and mechanical stone packs are not available, although mechanically emplaced packs have been found to be more efficient due to their increased compactness.

Prefabricated Packs

Prefabricated packs can consist of wood or concrete or wood and concrete blocks stacked to form a pillar or an open framework, which may or may not be filled. The behaviour of wooden cogs or chocks has been described by various authors[37,10,3]. A typical stress/strain relationship is shown in Fig. 4.

The behaviour of wooden packs under load has been described as follows:

(1) Elastic yield takes place in the early stages of compression.
(2) Further loading causes indentation of the chock pieces, followed by tensional failure along and across the chock pieces.
(3) After large compressions, contact occurs along the length of the chock pieces.
(4) When the load is released, recoveries of 40% may occur.

The properties of the constructions may be improved by including more pieces per layer, by using square section blocks, and by maintaining a width:height ratio of less that 0.65[37]. The effect of filling a chock with stone or dirt does not become apparent until sufficient yield has taken place to allow the fill to compact. At large strains, most of the filled chock resistance is provided by the compacted rock, the wood merely serving as lateral restraint.

Tests on concretes and modified concretes for use as timber substitutes in mine supports have been described by workers in the U.K. and South Africa[4,5,8,10,40]. Substitutes include:

(1) Lightweight aggregate blocks (Aglite);

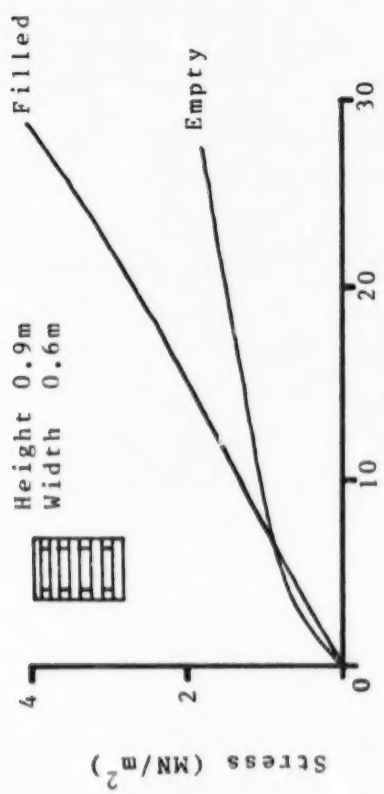

Figure 4 - Stress/strain characteristics of wooden chocks

(2) Lightweight aggregate blocks reinforced with wire or plastic internally and externally, and steel trays;

(3) Reinforced dense concrete blocks;

(4) Autoclaved aerated Concrete Blocks (Siporex, Celcon).

None of these substitutes has been found to be totally effective.

Aglite blocks have excellent early bearing characteristics, but collapse completely when the yield load is reached. Reinforcement has given good results, but is awkward to provide externally and problems have been encountered in distributing internal reinforcement evenly. Dense concrete blocks have a higher yield load but behave in the same way as Aglite blocks. They may also cause roof or floor penetration. Siporex and Celcon blocks show acceptable load/yield characteristics when externally reinforced but fail in the centre of the blocks, away from the reinforcement.

In order to combine the yielding properties of wood and the strength of concrete, composite packs have been constructed. Apart from limited trials in the United Kingdom and Holland with hardboard between layers of concrete blocks[41], most of the research has been done in South Africa. The stress/strain characteristics of examples of these types of prefabricated packs are given in Fig. 5, and the various pack performance parameters calculable from them are given in Table 3.

Monolithic Packs

Monolithic packs have one property which separates them from other pack types. They all increase in strength with time. In the case of anhydrite, this is caused by the completion of the hydration of calcium sulphate ($CaSO_4$) to the dihydrite form ($CaSO_4.2H_2O$) over a period of time. In the case of cement based packs, this is caused by the different rates of hydration of the various silicates which constitute the cement.

Anhydrite packs made from synthetic or natural anhydrite have been shown to have similar strength properties, and so no further differentiation will be made. The rate of formation of the dihydrite crystals is crucial to the early strength of an anhydrite pack and, as this is slow under normal conditions, 1% by weight of an accelerator consisting of Potassium and Ferrous Sulphate mixed in a 2:1 ratio (w/w) in the water is used. Typical strength/time properties are shown in Fig. 6.

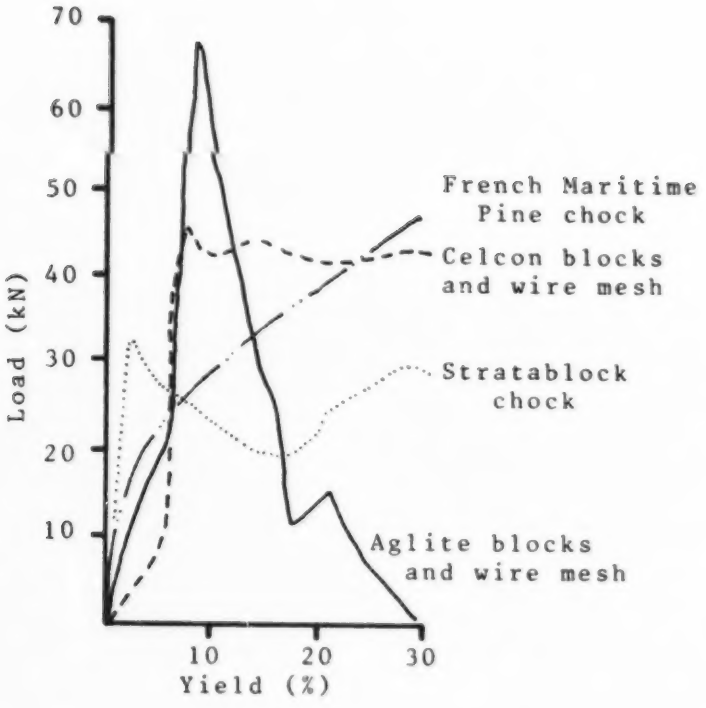

Figure 5 - Stress/strain characteristics of other prefabricated packs

Table 3 - Pack performance efficiencies of prefabricated packs (PPE_{30})

Material	Average Maximum Load (KN)	Yield Point Location	Performance Efficiency (%)
French Maritime Pine Chock	480	100	73
Stratablock Chock	360	7	72
Celcon Blocks and Wire Mesh Pack	470	26	77
Aglite Blocks and Wire Mesh Pack	670	29	33

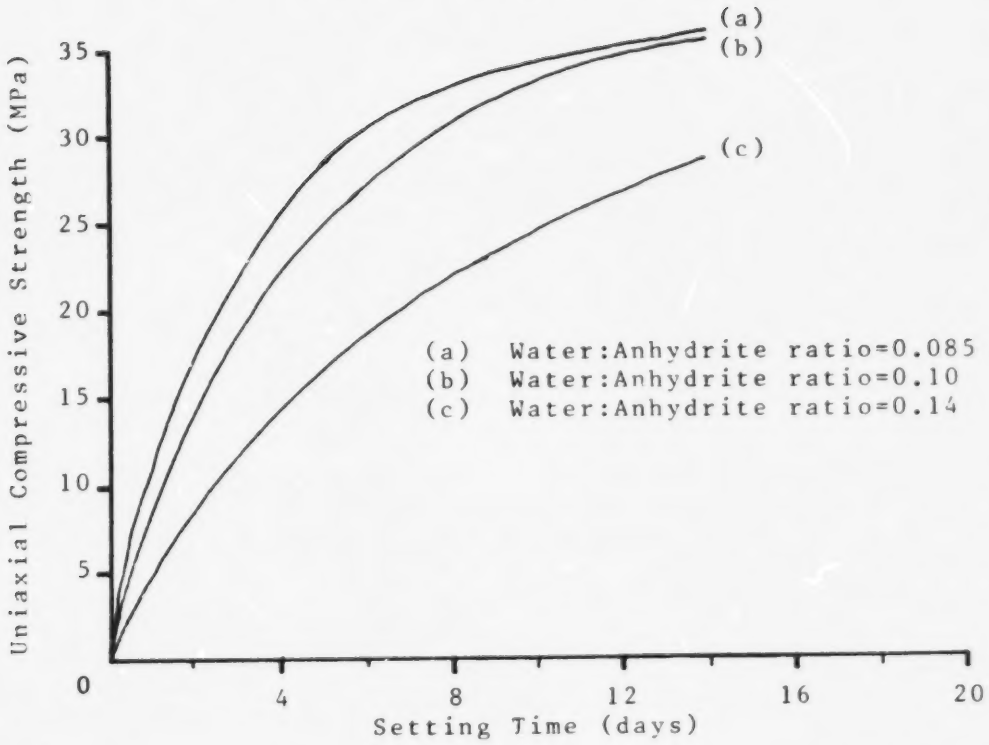

Figure 6 - Strength time properties of anhydrite packs

Arioglu and Dunham[42] have shown that the strength of an anhydrite pack depends on:

(1) the water anhydrite ratio,
(2) the quantity of accelerator,
(3) the effect of temperature, and
(4) the grain size.

The water/anhydrite ratio is normally maintained at 0.09-0.1:1 in practice. Reduction of the water content prevents complete hydration and reduces the final strength. Too much water gives lower early strengths, but the ultimate strength is the same as for the normal ratio (Fig. 7) and too much accelerator reduces strength at all stages.

The effect of temperature on strength is disputed but can be accounted for by differences in conditions, a drop in strength being caused by low humidities which result in excessive evaporation and therefore the early arrest of the hydration reaction. The grain size affects the rate of reaction and hence the heat given off, but it has no effect on the strength time curves.

Published data on the properties of cement packs is limited due to their recent appearance on the mining scene. The physical properties of 'Thyssen' type pumped pack have been determined by Carr[43] from Abernant colliery in the U.K., but these are lower in the later stages than those quoted by the manufacturer (0.75 MPa as opposed to 1.72-2.06 MPa claimed).

PACK LOAD ACCEPTANCE

The ultimate test of a pack's performance is its behaviour 'in-situ'. Early efforts to determine in-situ pack behaviour were hampered by inadequate load measuring devices, the investigations seeming to indicate that the pack load exceeded the cover load. This has recently been challenged, the belief being that the rear abutment does not rise above the cover load, but the argument has not been resolved.

FACTORS AFFECTING PACK PERFORMANCE

The factors that affect the performance of gateside packs can be considered to be:

(1) The properties of the pack material,
(2) The construction method employed,

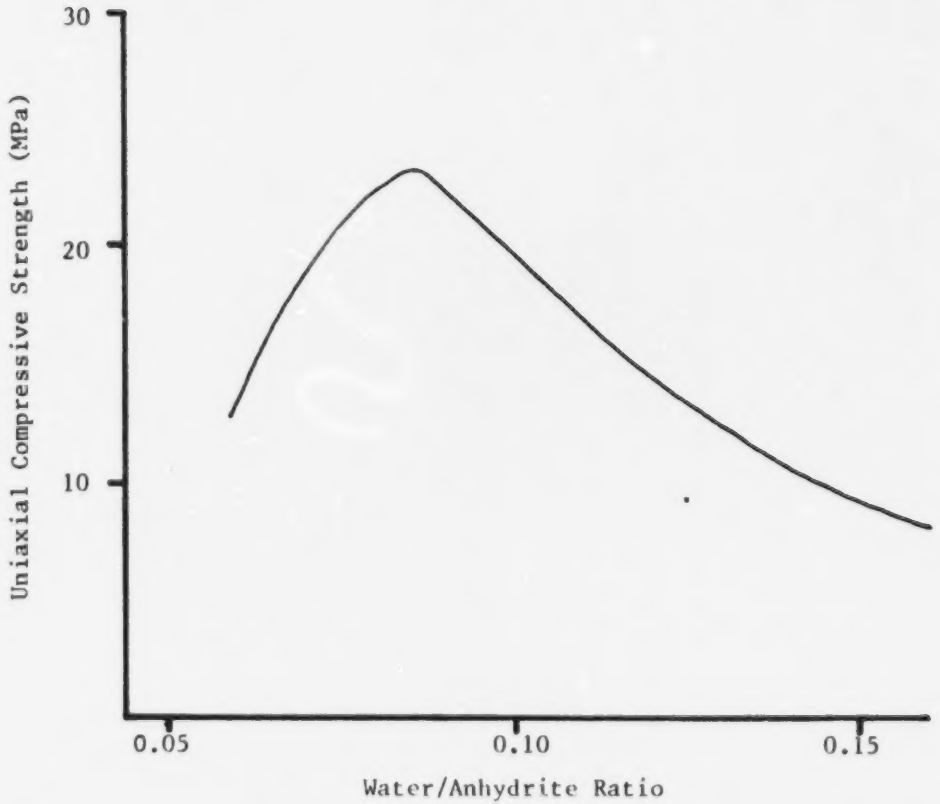

Figure 7 - Effect of water content on the strength of anhydrite packs (laboratory specimens tested 72 hours after mixing)

(3) The size of the pack,

(4) The rate of face advance, and

(5) The load environment.

The Properties of the Pack Material

The properties of the pack material determine the stress/strain relationship of the packs.

The Construction Method Employed

The pack must be constructed effectively otherwise it will not offer the planned degree of support. The effect of the varying degrees of compaction that can be achieved with stone packs, and hand or machine packs, has been described. Poor mining practise is often the cause of premature pack failure.

In order to have the greatest effect in reducing convergence, it is important to install the pack immediately behind the faceline. The further behind the faceline that a pack is installed, the more likely is large roof convergence, bed separation and subsequent degeneration of roof strata.

The Size of the Pack

The pack width is the most important parameter and the only one that can be effectively controlled. It must be consistent with stability, which may be a problem where extractions of over 2 m are concerned. Whittaker and Woodrow[11] have shown that in the case of uniformly distributed load over the pack area, there is little change in pack loading for widths of 3-10 m.

Very narrow packs will fail quickly unless made of a strong material, in which case floor and/or roof penetration will occur which itself will cause roadway deterioration. This is not so much of a problem where the bearing capacity of the proximate strata is relatively high, such as in West Germany.

The Rate of Face Advance

The rate of face advance may affect the pack performance in two ways. Firstly, if the method of packing cannot maintain the pack close to the face during rapid face movement, excessive convergence will occur in the

pack area as previously described. Secondly, the rate of face advance controls the rate of loading of the pack. If a pack exhibits 'creep' to any great extent, as timber packs do, excessive deterioration may occur during long periods of face standstill (weekends, holidays, etc).

The effect of rate of face advance on monolithic packs has not been investigated but in view of their time-dependent strength properties, it may be found that too rapid a face advance has a deleterious effect.

Load Environment

The amount of loading that the pack is subjected to depends on the load environment. This is dependent on the depth of cover, the presence of adjacent workings, and the proximate geology.

THE ADVANTAGES OF MONOLITHIC PACKING

A re-appraisal of face end techniques, particularly the system of packing, has been made necessary by the following factors[13]:

(1) The multitude of face-end systems currently in use,
(2) The differing natural circumstances of face ends,
(3) The difficulty of integrating the different face end operations and the required equipment with each mining system, and
(4) The inadequacy of the face end equipment, particularly with regard to quality and a capacity of performance.

The principle of transporting the pack medium from an outbye station to the prepared packhole, where it sets rapidly, may revolutionise this aspect of the face end operations. The disadvantages of traditional packing methods namely the supply of material, the inefficiency of the operation in terms of time and manpower, and the generally low strengths achieved by such packs, are all resolved by the use of one or other of the monolithic packing methods that have the following advantages:

(1) the decongestion of the face end,
(2) the convenient and economic transportation of materials, and
(3) the rate at which the packs can be installed, allowing rapid face advance.

Perhaps the only two major disadvantages of monolithic packing are that if a sealing of the packhole is required, it is often difficult without the use of expensive brattice bags and that the method does not allow a

convenient method of disposing of dirt and rippings. For these reasons, monolithic packing systems are ideally suited to Dual Life Retreat Roadways which serve fast moving faces producing little dirt and which require excellent support characteristics of the postextraction support system to maintain the roadway for second use.

The method of packing ultimately selected will depend on the system of working adopted, availability of materials, financial considerations and local conditions which dictate the properties of the required gateside pack.

CONCLUSIONS

The safe and efficient operation of longwall coal faces in the Sydney Coalfield and Europe is largely dependent on the quality and performance of the packs emplaced to protect the gateroad. After a long period of inactivity, research into packing methods and materials in the last decade has resulted in the prolific development of alternatives to traditional methods.

Of the new methods, monolithic packing appears to offer very attractive advantages over other methods and this is reflected in the expansion of its use from West Germany where it was first used in the form of pneumatically stowed anhydrite to the rest of Europe. In the U.K., the focus of attention is now largely on the low solids water based packs, although the recently developed Flyash/Cement mixtures would appear to offer a viable alternative in some circumstances.

The systems which, on the basis of this review, look attractive for use in the Sydney Coalfield are the low solids cement systems because of the long underground haulages required, or the Flyash/Cement mixtures which could use locally available materials at a marked cost reduction. Also available in Nova Scotia are supplies of anhydrite and gypsum, but these are some distance from the coalfield, and would require more careful storage and handling due to their cementitious nature.

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